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Two carbohydrate-electrolyte solutions (CE1, CE2) were evaluated for their ability to reduce the incidence of hypohydration in reservists participating in a field training exercise in hot weather (max T_{amb}=88°-100°F). Hydration status was monitored twice daily in sixty-one male and female soldiers who consumed one of four beverages (77±2°F) ad libitum: CE1, CE2, water (W), or flavored water (FW) placebo. Group W had the highest total percent incidence of urine specific gravity (USG) ≥ 1.030 (22%) whereas CE2 and FW placebo groups had the lowest (6% and 8%, respectively). Increased heat stress elevated both the group means for USG and the incidence of USG ≥ 1.030 despite enhanced fluid intake. CE2 and FW placebo were rated more favorably than CE1 and W, and this preference was reflected in the greater total fluid intakes in the CE2 and FW placebo groups. CE2 and FW placebo were effective in reducing the incidence of hypohydration during this field exercise.

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Hypohydration during field training in hot weather

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The views of the authors do not purport to reflect the positions of the Department of the Army or the Department of Defense. Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research. Citation of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

INTRODUCTION

Increasing body water deficits or hypohydration have long been associated with performance decrements and increased risk of heat injury. Individuals usually dehydrate voluntarily when fluid requirements are high and fluid consumption does not keep pace with fluid losses which may exceed 5% of body weight. Deficits of 2-3% are commonly observed during military field training exercises (1,2,3), laboratory experiments simulating desert training (4,5) and athletic events (6). The range of body water loss of importance to the military commander is from 2-6% of body weight because generalized discomfort, irritability, apathy, weariness, fatigue, headache, and dizziness are some of the symptoms associated with body weight losses greater than 2% (1,3). Other consequences of these levels of hypohydration are an elevation in heart rate and core temperature, a decrease in sweating (1,3), and degradations in performance, discipline and morale. Body weight losses greater than 6% occur less frequently, unless water is unavailable, because thirst is intense. Further decrements in work ability, dyspnea, cyanosis, delirium, and coma are consequences of more severe hypohydration (1).

Optimal physical performance in a hot environment is most likely to be maintained when fluid consumption matches fluid lost through sweating. Sohar (3) hypothesized that fluid consumption during work in the heat can be increased and the incidence of hypohydration reduced if palatable beverages are provided. Data from our studies (4,5,7) show that either flavoring or cooling

field grade water will enhance fluid consumption and reduce body water deficits, particularly in soldiers reluctant to drink. However, under conditions of high sweat and electrolyte loss, Ladell (8) suggested that water is not efficiently retained and rehydration will be incomplete unless solute lost in sweat is also replaced. Currently, disagreements persist on the requirement for supplemental electrolyte replacement during work in the heat particularly if total urinary and sweat losses are replaced in a timely manner by adequate diets.

In certain military contingencies, unacclimatized reservists may be activated and expected to perform their military duties immediately, as well as for prolonged periods of time. Reservists, accustomed to working in air-conditioned offices, may be translocated to hot environments and be required to perform heavy physical work. Under these conditions, carbohydrate-electrolyte beverages might be useful in maintaining fluid and solute balance and could theoretically reduce the severity of hypohydration and work degradation, particularly during deployment and the first 4-5 days post-deployment.

The purpose of this study was to evaluate hydration status in reservists undergoing field training in a hot environment. During the training, test subjects were assigned to one of four groups consuming ad libitum, water (W), flavored water (FW) placebo, or one of two flavored carbohydrate-electrolyte drinks (CE1 or CE2). The effects of voluntary consumption of the four beverages on urinary indices of dehydration and electrolyte excretion were assessed in these reservists undergoing an eight

day hot weather training exercise. Leithead and Pallister (9) had previously reported that 24 h urine samples of less than 500 ml typically had urine specific gravities (USG) $\geq$ 1.030, and Francesconi and coworkers (10) reported that consecutive samples with USG $\geq$ 1.030 may be clinically useful as a field expedient technique for detecting impending hypohydration. Therefore, a criterion of USG $\geq$ 1.030 was used as an index of hypohydration or impending hypohydration.

METHODS

Design:

Sixty-one (61) male and female reservists of the 44th Evacuation Hospital (Oklahoma City, OK and El Paso, TX), 807th Medical Brigade (11) participated in this study. Soldiers lived in tents for 8 days during the field training exercise at Fort Hood, TX during June 1988. During this time, their primary activities consisted of construction of an evacuation hospital, attending classroom sessions (Days 1-5) and participating in a field training exercise (FTX, Days 6-8).

The study design is outlined in the introductory article (11) of this series. Briefly, each subject consumed ad libitum one of four test beverages: one of two lemon-lime 2.5% carbohydrate-electrolyte solutions (CE1 and CE2) which differed mainly in potassium, magnesium and bicarbonate content, plain field chlorinated water (W), and a lemon-lime flavored water placebo (FW). While one of these four beverages was the principal drink available and consumed by each group, other

fluids were also drunk (11).

Measurements:

Two urine samples were collected each day for 8 days: the first urine voided upon rising (0600h, AM) and the second just before the evening meal (1630h, PM). Urine samples were immediately analyzed for specific gravity (American Optical, Refractometer, 10400A TS Meter) and dipstick (Ames N-Multistix). Aliquots were frozen in liquid nitrogen for subsequent flame photometric analysis of Na^+ and K^+ (Radiometer, Copenhagen FLM3).

Fluid intake and beverage acceptability were documented on self-reported forms for a daytime (0600-1630h) and an evening/overnight (1630-0600h) period corresponding to the urine collections (11,13).

Data were analyzed by two-way ANOVA with repeated measures to determine significance and Tukey's post hoc tests were run to establish where the differences occurred. Chi-square analysis was computed to establish whether the incidence of USG $\geq$ 1.030 and beverage group were related. Statistical significance was accepted at $p<0.05$.

RESULTS

Group mean specific gravities (AM and PM) are depicted in Figure 1. The results generally demonstrate that groups drinking CE2 or FW had lower USG than those consuming CE1 and W. These trends achieved statistical significance on Days 5 (AM) and 7 (AM) when USG of either CE1 or W was significantly ($p<0.05$)

greater than that of FW or CE2.

Although none of the groups displayed an average USG ≥ 1.030 at any sampling time (Figure 1), significant differences in the frequency of USG ≥ 1.030 during the 8 days of the field exercise were observed among the four groups. While only 8% of the total urine samples collected from soldiers consuming the FW placebo and 6% from those drinking CE2 had USG ≥ 1.030 during the 8 days (Figure 2), 13% and 22% of samples collected from CE1 and W groups, respectively, had USG ≥ 1.030. Based upon Chi-square analysis, the relationship between group and incidence of USG ≥ 1.030 was significant.

Increased heat stress (Days 1-4) elevated the group means for both USG (Figure 1) and the incidence of USG ≥ 1.030, particularly in CE1 and W (Figure 3). The number of urine samples meeting the criterion for hypohydration (USG ≥ 1.030) differed significantly between groups on Days 1,3,4, and 5. Urine samples having USG ≥ 1.030 from either the FW or CE2 groups were significantly fewer in number than for either the W or CE1 groups. A reduction in environmental temperature after Day 5 was accompanied by a decline in both the group mean USG's (Figure 1) and the incidence of elevated USG (Figure 3).

As shown in Figure 3, the percent incidence of USG ≥ 1.030 for groups W and CE1 peaked on the hottest day (Day 4). Likewise, on this hottest day we observed significantly lower incidences (8% and 0%) of USG ≥ 1.030 in the FW and CE2 groups compared to the CE1 (33%) or W (34%) groups (Figure 4, top). Subjects with a USG ≥ 1.030 consumed, on average, 23% less fluid

in the 24 h time period prior to the urine collection than those having a USG < 1.030 (Figure 4, bottom). Comparably lower fluid intakes were also noted in the subjects with a USG ≥ 1.030 for the 12 h period preceding the urine collection.

Urinary Na^+/K^+ ratios were not correlated with indices of hypohydration (Figure 5). Generally, the CE1 and CE2 groups manifested the highest levels of Na^+ excretion, and excretion of Na^+ tracked Na^+ intake quite closely (12,13). Likewise, the CE1 group had the highest K^+ intake, and this was clearly reflected in the urinary K^+ excretion.

DISCUSSION

Because caloric consumption and activity level certainly affect body weight, body weight fluctuations alone may not adequately reflect hydration status during long term field studies. However, studies (9,10) have shown that increases in urine specific gravity (USG) can indicate hypohydration, impending hypohydration, or the activation of renal mechanisms preventing significant hypohydration. In the present study, we used USG ≥ 1.030 as a field expedient criterion of hypohydration. None of the groups displayed a mean USG ≥ 1.030 at any of the 15 sampling times during the eight days. This was unexpected because of the high level of physical activity of many of these troops from about 0800-2000 hr during the first five days of field training (constructing and equipping a field hospital). However, during the prior three years this unit has emphasized the importance of water discipline in its hot weather training,

and this emphasis was evidently effective in maintaining hydration and minimizing heat casualties during this exercise. Nonetheless, the data indicated a trend toward increasing USG with elevated wet bulb globe temperature (WBGT) (Figure 3).

It is noteworthy that the number of urine samples exceeding the criterion for hypohydration differed significantly between the groups particularly during the first 5 days when physical activity was heavy. The incidence of USG $\geq$ 1.030 in either the CE1 or W group increased with increasingly oppressive ambient conditions, peaked on the hottest day (Day 4: max d.b. = 101°F, max WBGT = 90.3°F), and then declined most likely as a result of reduced environmental heat stress, lessened work load and adequate rehydration. In comparison, the frequency of USG $\geq$ 1.030 in either FW placebo or CE2 group was consistently lower.

Temperature and flavor of beverages are two important determinants of fluid consumption (1,3,4,7,14). The palatability of drinking water is particularly important when fluid requirements are high (e.g. the first four days of the present study) since physiological and psychological decrements and the increased risk of heat illness are associated with large water losses without adequate replacement. When given the choice of drinking the FW or plain water (W), subjects drank 10-fold more of the FW than W although the FW was usually warmer (79°F) than W (75°F) (12). Previous studies have shown that cooler beverages are more acceptable than warmer (1,3,4,5), and cool water may be the most preferable beverage when large quantities must be consumed (1,3). While CE2 was rated most favorably,

acceptability of CE1 was significantly lower than either W or FW. Ratings of these four beverages were reflected in both the higher total daily intakes of CE2 and FW (CE2 > FW $\geq$ W > CE1) and the overall lower incidence of hypohydration in the CE2 and FW groups (CE2 $\leq$ FW < CE1 < W) (12). These data indicate that soldiers preferred the colored flavored water over the cooler field chlorinated water (W) during these training exercises.

Our data suggest that the level of dietary consumption of electrolytes was the most critical factor in determining urinary excretion levels. As anticipated, both CE1 and CE2 groups manifested the highest levels of urinary Na^+ excretion due to the electrolyte composition of the beverages. Urinary Na^+ excretion may also be altered by heat acclimation, sweat secretion and hydration status. Likewise, the increased K^+ level of CE1 relative to CE2 was reflected in the greater K^+ excretion of this group, and contributed to the increased urinary Na^+/K^+ ratio of the CE2 group versus the CE1 group. We have concluded that under the conditions of this study in which physical activity was generally moderate, heat stress was variable, and meals were consistently available and eaten, carbohydrate-electrolyte supplemented beverages were probably unnecessary.

Sohar and associates (3) reported that even mild hypohydration may cause discomfort, fatigue, irritability, and performance decrements. Because data were collected twice daily and investigators had unlimited access to worksites, we had ample opportunity to observe subject behavior. On several of the hottest days (Days 2-5) when physical labor was intense, eleven

of our subjects not only had USG $\geq$ 1.030 but also displayed behavioral symptoms of mild hypohydration. For example, a 19 yr old hard-working enlisted male worked daily setting up hospital tents and on one day was assigned additional duty as a 12-hour (0600-1800) guard. On several occasions we observed in this individual the symptomatology of 3-5% hypohydration including aggressive behavior, impatience, anorexia, severe headache, and stumbling. On almost all days, he had USG between 1.030 and 1.036, and low urinary volume and Na^+/K^+ ratios. We encouraged this soldier to consume both adequate fluid and food, and this eventually reduced the hypohydration (USG = 1.028) and improved his behavior.

The results of this study indicate that during field training under mild to severe heat stress, voluntary fluid intake was enhanced and, consequently, the incidence of hypohydration was lessened, by coloring and flavoring (FW placebo) the field drinking water. Under the environmental work conditions of this study, carbohydrate-electrolyte supplementation in beverages was probably unnecessary because meals were consistently consumed.

FIGURE LEGENDS

Figure 1. Average urinary specific gravity in each of four test beverage groups expressed as a function of sampling time (AM or PM) and day. $\downarrow$ depicts statistically significant ($p<0.05$) differences between CE1 or W and CE2 or FW.

Figure 2. Total percent incidence of urinary specific gravity (USG) $\geq$ 1.030 for each of four test beverage groups. $\downarrow$ depicts significant ($p<0.05$) differences between CE1 or W and CE2 or FW.

Figure 3. Maximum dry bulb and wet bulb globe temperatures (top panel) and percent incidence of USG $\geq$ 1.030 are plotted as functions of day. $\downarrow$ represents significant ($p<0.05$) differences between CE1 or W and CE2 or FW.

Figure 4. Top panel depicts USG $\geq$ 1.030 of day 4 for each of four test beverage groups. $\downarrow$ represents significant difference ($p<0.05$) between CE1 or W and CE2 or FW. Bottom panel shows comparison of Day 4 fluid intakes for subjects having USG < 1.030 to those having USG $\geq$ 1.030 for each of four test beverage groups. ✱ depicts statistical significance ($p<0.05$) between USG < 1.030 and $\geq$ 1.030 for the W group.

Figure 5. Average urinary Na^+/K^+ ratio (top panel), Na^+ intake (middle panel) and K^+ intake (bottom panel) plotted as a function of day for each of the four beverage groups. $\downarrow$ represents significant difference ($p<0.05$) between CE1 or W and CE2 or FW. $\uparrow$ represents significant difference ($p<0.05$) between CE1 and W.

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Fig 1

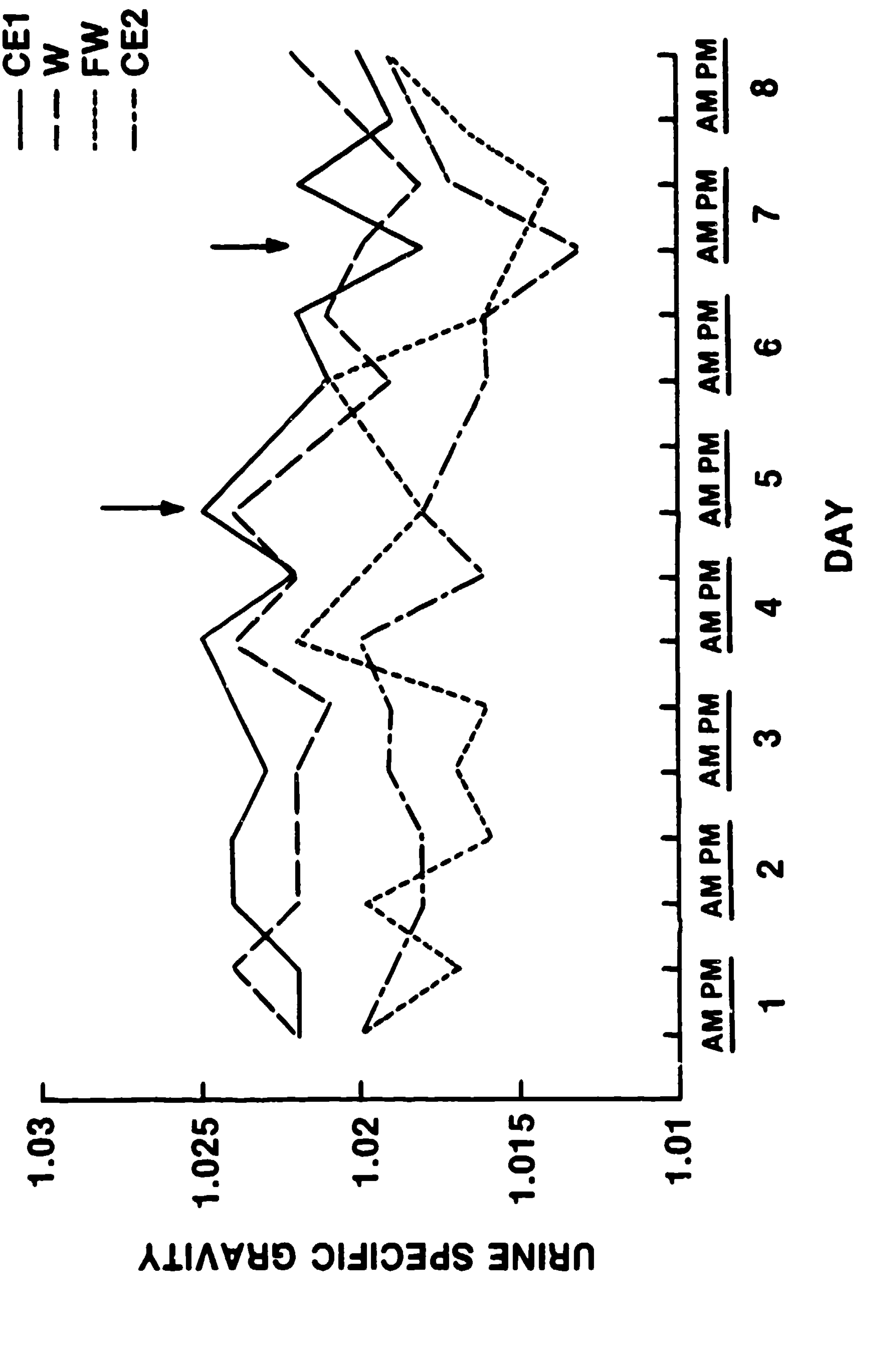
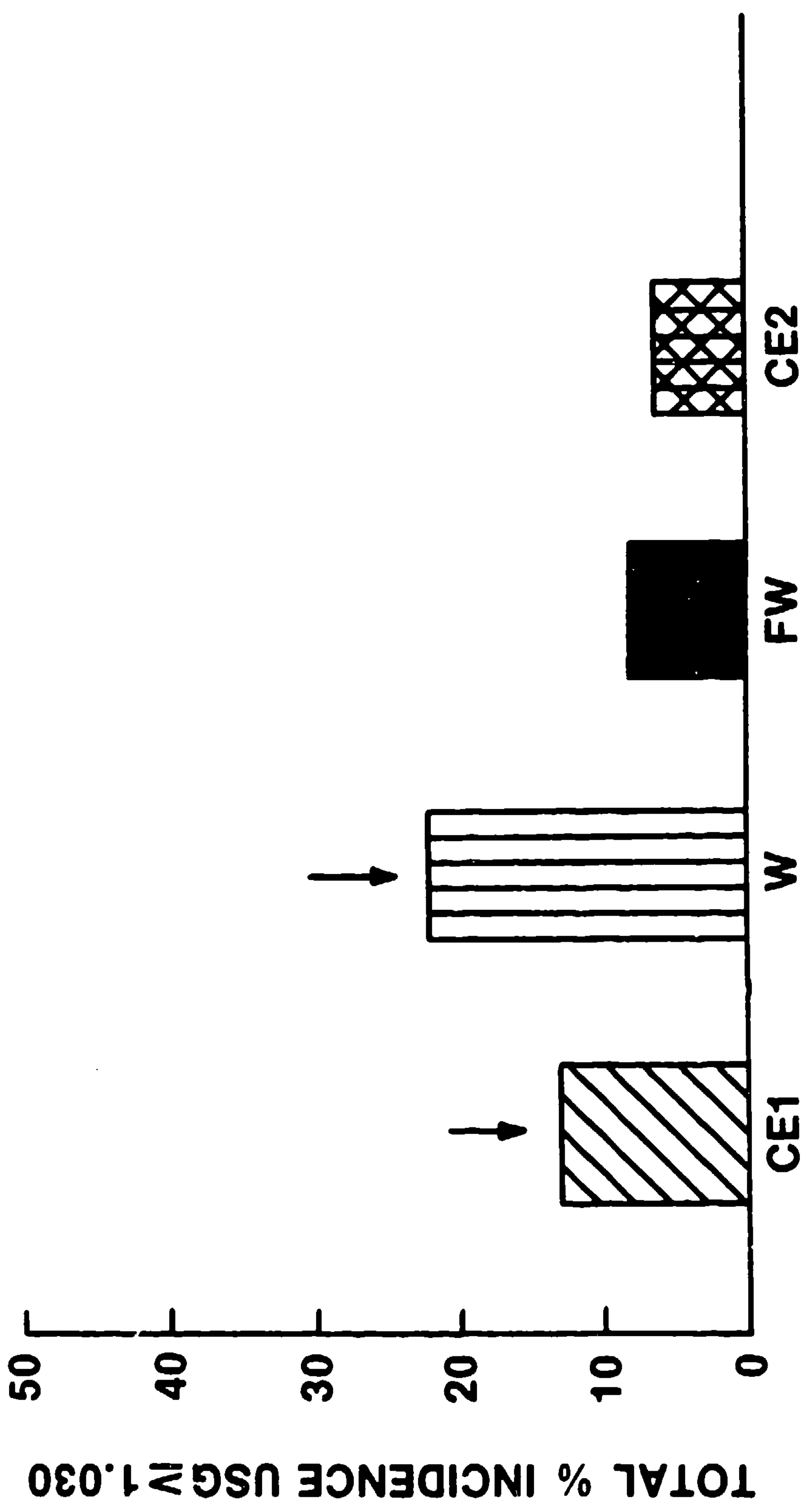

CE1
W
FW
CE2
1.03
1.025
1.02
1.015
1.01
URINE SPECIFIC GRAVITY
AM PM
1
2
3
4
5
6
7
8
DAY

Fig 2



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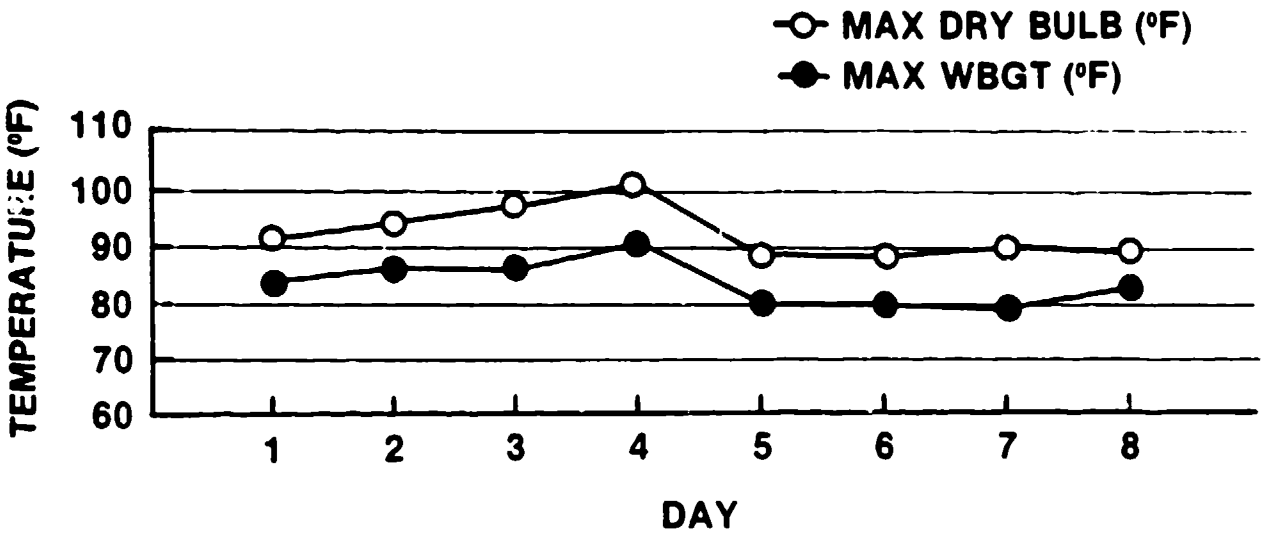
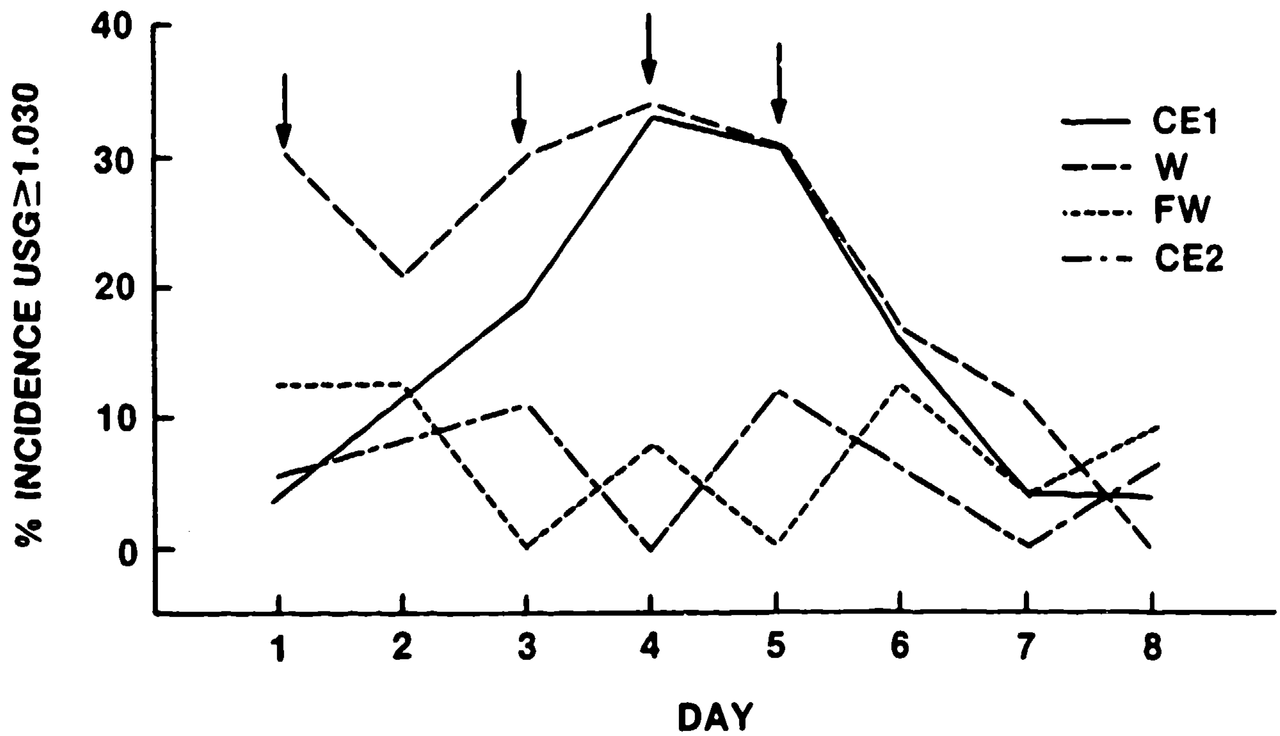
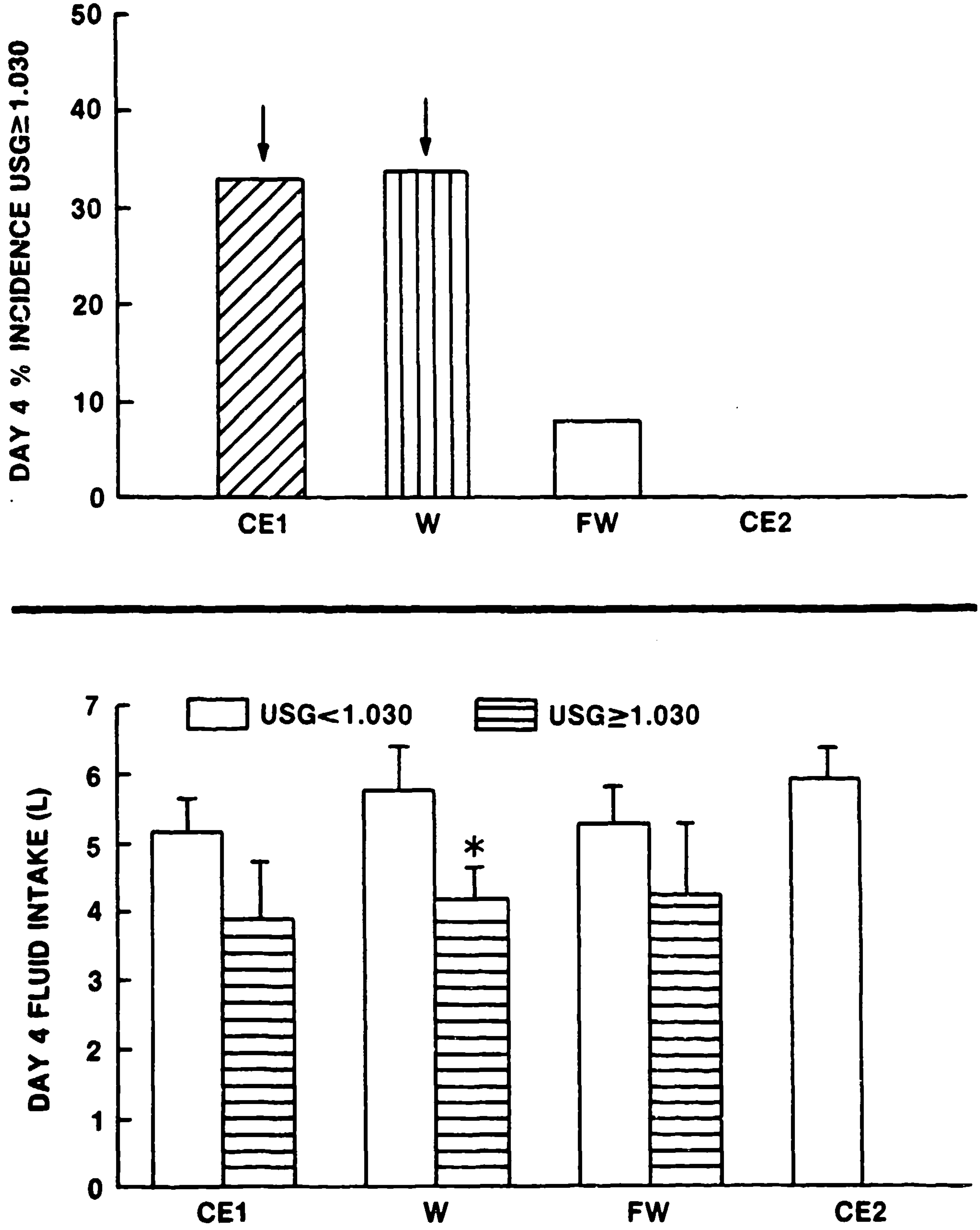


MAX DRY BULB (°F)
MAX WBGT (°F)
TEMPERATURE (°F)
110
100
90
80
70
60
1
2
3
4
5
6
7
8
DAY



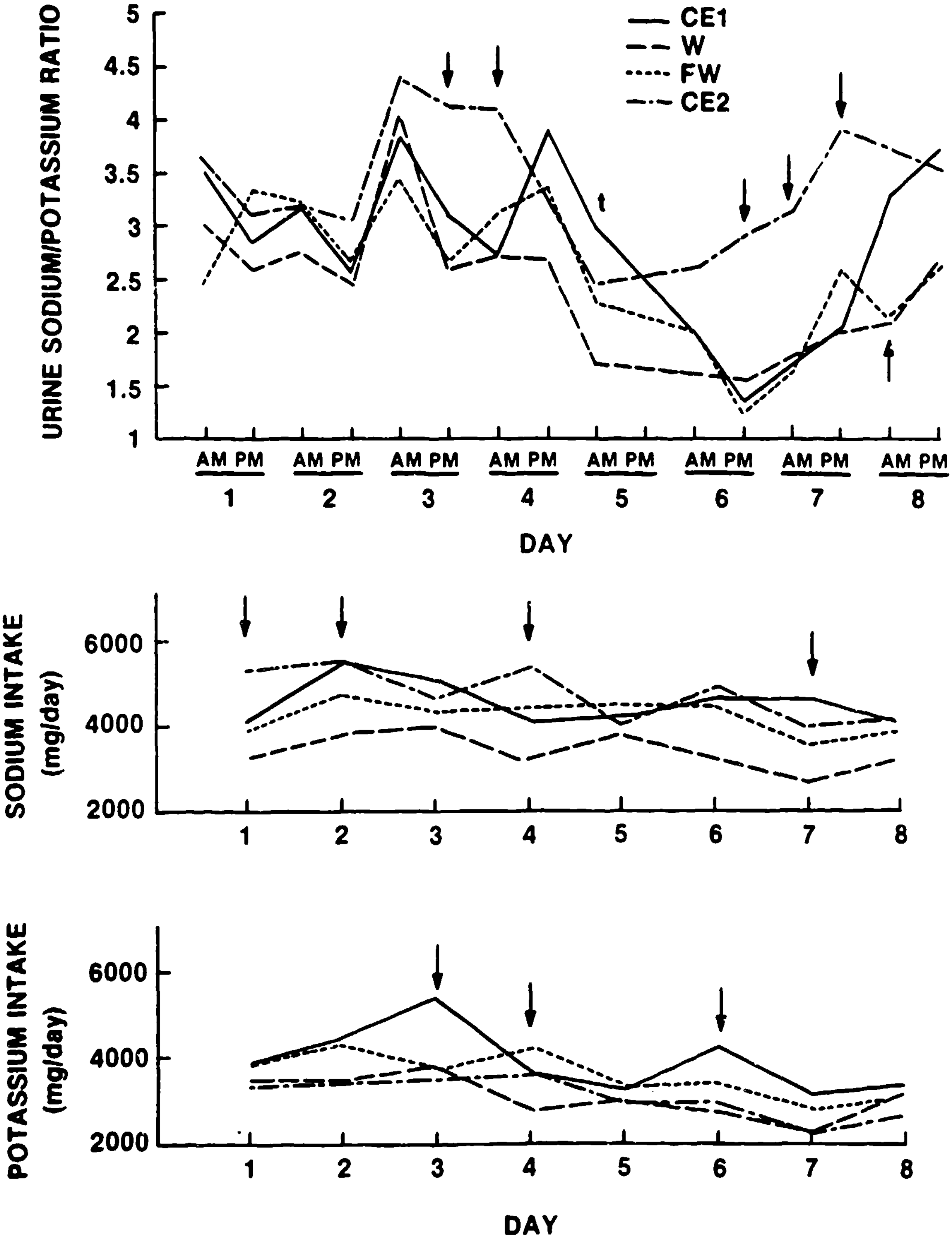
% INCIDENCE USG≥1.030
40
30
20
10
0
CE1
W
FW
CE2
1
2
3
4
5
6
7
8
DAY

Fig 4



DAY 4 % INCIDENCE USG≥1.030
50
40
30
20
10
0
CE1
W
FW
CE2
USG<1.030
USG≥1.030
DAY 4 FLUID INTAKE (L)
7
6
5
4
3
2
1
0
*
CE1
W
FW
CE2

Fig 5


CE1
W
FW
CE2
URINE SODIUM/POTASSIUM RATIO
5
4.5
4
3.5
3
2.5
2
1.5
1
AM PM
1
2
3
4
5
6
7
8
DAY
SODIUM INTAKE (mg/day)
6000
4000
2000
POTASSIUM INTAKE (mg/day)
DAY

END

FILMED

1-90

DTIC